

What is claimed is:

1. A warning system with vibration for an automotive vehicle comprising:

a sensing section detecting operational states of the vehicle;

5 a wheel actuator variably adjusting road wheel speed of a road wheel;  
and

a control unit configured to be connected electrically to the sensing  
section and the wheel actuator, for automatically controlling  
fluctuations in the road wheel speed to generate vibrations in the  
10 vehicle based on the operational states of the vehicle.

2. The warning system as claimed in claim 1, wherein:

the control unit comprises a deviation determination section  
programmed to determine a degree of lane deviation of the vehicle  
15 from a current driving lane based on the operational states of the  
vehicle and to determine whether there is a possibility of lane  
deviation of the vehicle based on the degree of lane deviation; and  
the control unit produces fluctuations in the road wheel speed to  
generate vibrations in the vehicle, when it is determined that there  
20 is a possibility of lane deviation of the vehicle.

3. The warning system as claimed in claim 2, wherein:

the wheel actuator regulates wheel torque applied to the road wheel  
for variably adjusting the road wheel speed; and  
25 the control unit comprises a wheel torque control section programmed  
to control fluctuations in the wheel torque to control the fluctuations  
in the road wheel speed.

4. The warning system as claimed in claim 3, wherein:

the wheel actuator comprises a hydraulic modulator hydraulically connected to a wheel brake cylinder at the road wheel for regulating braking torque applied to the road wheel.

5        5. The warning system as claimed in claim 3, wherein:

the wheel actuator comprises a driving torque controller regulating driving torque applied to the road wheel.

6. The warning system as claimed in claim 3, wherein:

10       the sensing section detects a vehicle speed; and

the wheel torque control section controls the fluctuations in the wheel torque to generate vibrations in the vehicle based on the vehicle speed.

15       7. The warning system as claimed in claim 6, wherein:

a period of the fluctuations in the wheel torque is determined based on at least one of the vehicle speed and the degree of lane deviation of the vehicle.

20       8. The warning system as claimed in claim 7, wherein:

the period of the fluctuations in the wheel torque is decreased with increasing vehicle speed.

9. The warning system as claimed in claim 7, wherein:

25       the period of the fluctuations in the wheel torque is decreased with increasing degree of lane deviation of the vehicle.

10. The warning system as claimed in claim 6, wherein:

30       an amplitude of the fluctuations in the wheel torque is determined based on at least one of the vehicle speed and the degree of lane deviation of the vehicle.

11. The warning system as claimed in claim 10, wherein:  
the amplitude of the fluctuations in the wheel torque is increased with  
increasing vehicle speed.

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12. The warning system as claimed in claim 10, wherein:  
the amplitude of the fluctuations in the wheel torque is increased with  
increasing degree of lane deviation of the vehicle.

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13. The warning system as claimed in claim 6, wherein:  
which individual wheel torque applied to each road wheel of the  
vehicle is fluctuated is determined based on at least one of the  
vehicle speed and the degree of lane deviation of the vehicle.

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14. The warning system as claimed in claim 13, wherein:  
the wheel torque control section produces fluctuations in both wheel  
torques applied to rear road wheels, if the vehicle speed exceeds a  
predetermined threshold speed or the degree of lane deviation of  
the vehicle exceeds a predetermined threshold degree.

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15. The warning system as claimed in claim 3, wherein:  
the wheel torque control section produces fluctuations in wheel torque  
applied to a road wheel at one of left and right sides of the vehicle  
where the deviation determination section determines that there is  
a possibility of lane deviation of the vehicle.

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16. The warning system as claimed in claim 15, wherein:  
the wheel torque control section produces fluctuations in wheel torque  
applied to a rear road wheel.

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17. The warning system as claimed in claim 3, wherein:

the wheel torque control section controls individually wheel torque applied to each road wheel independently of manual operation of wheel torque.

5        18. The warning system as claimed in claim 2, wherein:  
the control unit comprises a rumble strip determination section  
programmed to determine whether a road wheel of the vehicle is  
passing on a rumble strip with road irregularities continuously  
provided on a road shoulder; and  
10       the control unit controls the fluctuations in the road wheel speed  
based on the determination by the rumble strip determination  
section.

15       19. The warning system as claimed in claim 18, wherein:  
the control unit inhibits producing fluctuations in the road wheel speed,  
when it is determined that a road wheel of the vehicle is passing on  
a rumble strip with road irregularities continuously provided on a  
road shoulder.

20       20. The warning system as claimed in claim 18, wherein:  
the sensing section detects a wheel acceleration of a road wheel; and  
the rumble strip determination section determines that the road  
wheel is passing on a rumble strip with road irregularities  
continuously provided on a road shoulder, when fluctuations in the  
25       wheel acceleration are periodic with an amplitude greater than a  
threshold acceleration during a duration longer than a threshold  
duration.

30       21. The warning system as claimed in claim 2, wherein:  
the sensing section detects a vehicle speed, a heading angle of the  
vehicle with reference to a direction of the current driving lane, a

lateral displacement of the vehicle with reference to a central position of the current driving lane, and a curvature of the current driving lane;

5 the deviation determination section determines a future lateral displacement estimate of the vehicle from the central position of the current driving lane as a degree of lane deviation of the vehicle based on the vehicle speed, the heading angle, the lateral displacement, and the curvature of the current driving lane; and  
10 the deviation determination section determines that there is a possibility of lane deviation of the vehicle when the future lateral displacement estimate exceeds a predetermined lane deviation warning threshold displacement.

22. The warning system as claimed in claim 2, wherein:

15 the deviation determination section determines whether there is a possibility of imminent lane deviation of the vehicle based on the degree of lane deviation; and  
the control unit comprises a deviation prevention section programmed to control a yawing moment applied to the vehicle in a  
20 direction opposite to a direction of a potential lane deviation when it is determined that there is a possibility of imminent lane deviation of the vehicle.

23. The warning system as claimed in claim 22, wherein:

25 the deviation prevention section produces a wheel torque difference between a left side and a right side of the vehicle to control the yawing moment.

24. The warning system as claimed in claim 23, wherein:

30 the deviation prevention section produces a wheel torque difference between a left rear road wheel and a right rear road wheel to control

the yawing moment when a desired yawing moment is smaller than a predetermined threshold yawing moment.

25. The warning system as claimed in claim 22 further comprising:  
5 a steering actuator operatively associated with a steering shaft and connected electrically to the control unit for regulating an additional steering torque to produce the yawing moment.
26. The warning system as claimed in claim 22, wherein:  
10 the sensing section detects a vehicle speed, a heading angle of the vehicle with reference to a direction of the current driving lane, a lateral displacement of the vehicle with reference to a central position of the current driving lane, and a curvature of the current driving lane;  
15 the deviation determination section determines a future lateral displacement estimate of the vehicle from the central position of the current driving lane as a degree of lane deviation of the vehicle based on the vehicle speed, the heading angle, the lateral displacement, and the curvature of the current driving lane; and  
20 the deviation determination section determines that there is a possibility of imminent lane deviation of the vehicle when the future lateral displacement estimate exceeds a predetermined lane deviation prevention threshold displacement.
- 25 27. The warning system as claimed in claim 26, wherein:  
the deviation determination section determines that there is a possibility of lane deviation of the vehicle when the future lateral displacement estimate exceeds a predetermined lane deviation warning threshold displacement; and

the predetermined lane deviation prevention threshold displacement is greater than the predetermined lane deviation warning threshold displacement.

5        28. The warning system as claimed in claim 1, wherein:  
the wheel actuator regulates wheel torque applied to the road wheel  
for variably adjusting the road wheel speed; and  
the control unit comprises a wheel torque control section programmed  
to control fluctuations in the wheel torque to control the fluctuations  
10        in the road wheel speed.

29. A warning system with vibration for an automotive vehicle  
comprising:  
sensing means for detecting operational states of the vehicle;  
15        wheel actuating means for variably adjusting road wheel speed of a  
road wheel; and  
control means for automatically controlling fluctuations in the road  
wheel speed to generate vibrations in the vehicle based on the  
operational states of the vehicle.

20        30. A method of warning with vibration for an automotive vehicle  
comprising:  
detecting operational states of the vehicle;  
determining a degree of lane deviation of the vehicle from a current  
25        driving lane based on the operational states of the vehicle;  
determining whether there is a possibility of lane deviation of the  
vehicle based on the degree of lane deviation; and  
producing fluctuations in a road wheel speed to generating vibrations  
in the vehicle when it is determined that there is a possibility of lane  
30        deviation of the vehicle.